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Efficacy of Learning Disorder Treatment for Reading or Mathematics Disorders: An Open Study

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Objectives: This study aimed to identify the effectiveness of treatment programs for children with reading (RD) or mathematics disorders (MD). Structured treatment programs were developed to improve phonological awareness and number sense among children and adolescents with RD or MD, respectively, and the effectiveness of the learning disorder treatment programs were evaluated.
Methods: We used standardized, objective diagnostic, and evaluation tools not only to recruit participants with RD, MD, or comorbid attention deficit and hyperactivity disorder, but also to assess the effectiveness of the treatments regarding both improved core neurocognitive deficits of RD or MD and academic achievement. Forty children with RD or MD received one-on-one treatments from therapists.
Results: In the RD group, treatment effects were observed in all subtests. In the word and paragraph reading tests, the accuracy rates and fluency improved. The results of the phonological working memory test, word–sound correspondence test, and rapid automatic naming tests also improved. In the MD group, the accuracy rate and fluency on the arithmetic test improved. An increase in the accuracy rate in the size and distance comparison tests and a decrease in the error rate in the estimation test were also observed. However, there were no improvements in reaction time in these subtests.
Conclusion: Learning disorder treatment programs that focus on improving phonological awareness or number sense in children with RD or MD improved achievement, phonological awareness, and number sense.

Keywords: Reading disorder; Mathematics disorders; Specific learning disorder; Dyslexia; Dyscalculia; Learning disorder treatment.

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INTRODUCTION

To conduct any academic work, basic learning skills such as reading, writing, and calculating are fundamental. Around 5%−15% of school-aged children have a specific learning disorder (SLD), characterized by a lack of basic learning skills [1]. According to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5), SLD is a persistent difficulty in learning and using academic skills related to reading, writing, or mathematics that originates from organic causes. Intellectual disability, lack of educational opportunities, neurological or physical diseases, and environmental restrictions as etiologies of SLD should be excluded [2].

Reading is the most important basic learning skill in study, and reading disorder (RD) is characterized by poor accuracy and fluency in reading, or difficulty in reading comprehension. Among types of RD, dyslexia is characterized by difficulty in decoding letters into corresponding speech sounds without verbal understanding ability. The prevalence of RD and dyslexia has been reported to be 4%−9% [3] and 5%−17.5% [4] by different studies. The prevalence of RD and dyslexia among Korean children using Hangul was 9.2% and 5.6%, respectively [5], these percentages are similar to those in countries using other languages. The major causes of dyslexia are deficits in phonological awareness and processing ability [6]. The cognitive causes of mathematics disorder (MD) are a lack of number sense, the inability to use long-term memory for storing and retrieving simple math facts, or slow and inaccurate calculation [1]. Among types of MD, math insufficiency due to a lack of number sense is classified as dyscalculia [2]. Number sense is the ability to understand spatial representation and a conceptual understanding of numbers. It is highly related to mathematical achievement, numerical information processing, simple math facts memorization, and accurate and fluent calculation performance [7,8]. The prevalence of MD in other countries and in Korea has been reported to be 3%−7% [9,10] and 9.3% [5], respectively. The prevalence of dyscalculia, as reported in Korea, is 4.0% [5].

Children with RD find it very difficult to achieve the academic tasks that become increasingly difficult as they advance through school; moreover, these difficulties persist throughout their lives [11]. They also tend to have more psychological problems, such as anxiety or depression [12]. Mathematical ability has a significant impact on not only general academic achievement, but also on employability and socioeconomic status after graduation [13-15]. Because it is known that RD and MD can be improved by intensive early treatments, early detection and treatment are crucial and highly recommended [16,17].

Studies on SLD treatments have been conducted worldwide. Previous studies that focused on phonological awareness training for children with RD revealed improvements in word recognition and reading fluency after the treatments [18,19]. Moreover, when treatments focused on number sense training for students with MD or math underachievers, number sense fluency and basic arithmetic performance improved [10,20]. Until now, however, most studies on improving basic learning skills in reading or mathematics had several important limitations.

First, methods of identifying potential study participants were ambiguous. Participants were not assessed using accurate and objective inclusion processes. Furthermore, most studies did not apply internationally accepted diagnostic criteria, such as the DSM, and did not use objective intelligence tests, such as the Weschler Intelligence Scale for Children, to exclude intellectual disability or objective and standardized diagnostic assessment tools for SLD diagnosis. Primarily, experts' systematic history taking, mental status examination, and structured diagnostic interview tools for psychiatric diagnosis were not applied; these steps are essential not only to determine SLD, but also to rule out emotional, environmental, and physical factors. Additionally, assessments of attention deficits, which can exert a strong influence on participants' learning, have rarely been conducted.

Second, most existing studies did not use objective assessment tools to evaluate treatment effects. Specifically, previous studies seldom objectively evaluated changes in phonological awareness or number sense, which are known to be essential causes of RD and MD, respectively.

Third, the programs used in these studies were diverse and inconsistent. To overcome these limitations, this study aimed to verify the effectiveness of structured learning disorder treatment programs using standardized and objective diagnostic and assessment tools.

METHODS

Participants

This study was conducted at a child and adolescent psychiatric clinic from 2017 to 2023, and included 25 children with RD aged 6–11 years and 15 children and adolescents with MD, aged 7–14 years. All participants or their guardians agreed to participate and provided written and informed consent. The study group was diagnosed by a child and adolescent psychiatrist using the Kiddie-Schedule for Affective Disorders and Schizophrenia-Present and lifetime version-Korean version (K-SADS-PL-K) [21], based on the DSM-IV diagnostic system.

Assessments

Intelligence assessment

We used the Korean-Wechsler Intelligence Scale for Children–Fourth Edition (K-WISC-IV) [22]. This scale was designed to evaluate the intellectual abilities of children and adolescents aged 6–16 years, and it comprises 10 main tests and 5 supplementary tests. The factors can be divided into the following four categories: Language Comprehension, Perceptual Reasoning, Working Memory, and Processing Speed.

Learning ability assessments

Reading assessment

To diagnose RD and evaluate reading capability and related cognitive functions, the Comprehensive Learning Test–Reading (CLT-R) was used [23]. This computerized test evaluates reading achievement and reading-related cognitive processing abilities, including the Word Attack/Nonword Decoding test, the Paragraph Reading Fluency test, the Nonword Repetition test, the Rapid Automatized Naming–numbers, letters, objects (RAN) test, and the Letter–Sound Matching test.

Mathematic assessment

To determine whether the participant had MD or not, and to assess the level of math achievement and associated cognitive function, the Comprehensive Learning Test–Mathematics (CLT-M) was applied [24]. The test consists of seven subtests that evaluate math-related cognitive processing, including the Numerical Comparison test–Magnitude, the Numerical Comparison test–Distance, the Enumeration of Dot Group test, and the Number Line Estimation test, as well as the Whole Number Computation test that measures math achievement.

Attention assessment

The Comprehensive Attention Test (CAT) was used to evaluate attention, one of the most important cognitive functions that affect learning [25]. The CAT is a computerized Comprehensive Attention Test for Koreans aged 4 to 50s and consists of six subtests that measure Simple Selective Attention (visual and auditory), Inhibitory Sustained Attention, Interference Selective Attention, Divided Attention, and Working Memory.

SLD treatment programs

Treatment program for RD

This study used a basic workbook and teaching guide for RD: the "*Comprehensive Literacy Program for Korean dyslexics*" [26]. The material was designed to remediate the reading difficulties of children and adolescents with RD and has been the most widely used in Korea. This program is based upon the treatment methods of the Lindamood Phoneme Sequencing Program for Reading, Spelling, and Speech in the phonological awareness section, as well as the Wilson Reading System in the phonics and decoding sections used in the United States.

Treatment program for MD

"*Numeracy for all*" [27] was used as a basic workbook and teaching guide for children and adolescents with MD in this study. This program refers to "Math Recovery"—an Australian guidance program for underachievers in math—and "Building Blocks"—a National Science Foundation-funded early math program. It was developed for children with math difficulties that are related to the underdevelopment of number sense [16,28] and was reorganized to be in line with Douglas H. Clements' theory of learning trajectories [29]. It aims to improve both number sense, by emphasizing subitizing ability and number relations in a step-by-step manner, as well as calculation ability by introducing various calculation strategies and increasing flexibility in strategy selection. This system is also widely used in Korea.

Procedure

This study was conducted after obtaining approval from the Public Institutional Review Board designated by the Ministry of Health and Welfare (IRB No. P01-202111-12-003). Information about the study was provided to the children and adolescents who were going to participate in the study, and their guardians, and written consent and ascent were obtained. A child and adolescent psychiatrist conducted two in-depth clinical interviews with mental status examinations to assess the physical and mental health problems and environmental conditions of the study participants. Additionally, the K-SADS-PL-K was used to make clinical diagnoses. Two experienced clinical psychologists conducted an intelligence assessment using the K-WISC-IV; those with an IQ of 70 or lower were excluded from the study. Other experienced evaluators administered the CLT-R, CLT-M, and CAT, one-on-one. Finally, a child and adolescent psychiatrist confirmed the diagnoses of the research participants, based on the clinical data and test results. When participants had comorbid attention deficit hyperactivity disorder (ADHD) that was significant enough to require treatment, medication to control the ADHD symptoms, parental education, or cognitive behavioral therapy were administered beforehand. After the participant's ADHD symptoms stabilized, one-on-one learning disorder treatment was administered by the therapists. Reading treatments were provided for 50 minutes twice a week for an average of 22.5 (standard deviation [SD] 14.2) months, and math treatments were provided for 50 minutes once or twice a week, for an average of 18.0 (SD 10.4) months. To verify the effectiveness of the learning disorder treatments, the CLT-R and CLT-M were conducted before and after the treatments.

Statistical analysis

Descriptive statistics were used to analyze the demographic and clinical data of the participants. A Wilcoxon signed-rank test was used to verify the treatment effect, and the significance level of p-value was set at 0.05. All analyses were performed using SPSS software (version 21.0; IBM Corp., Armonk, NY, USA).

RESULTS

Demographic information

Among the 25 children who participated in the RD treatment program, 17 (68.0%) were boys and 21 (84.0%) were elementary school students (Table 1). Their average number of years of education was 1.96 (SD 1.31). All participants were concurrently diagnosed with RD, 22 (88.0%) with ADHD, and 12 (48.0%) with MD.

A total of 15 students participated in the MD treatment program, of which 13 (86.7%) were elementary school students (Table 1). The average years of education was 3.33 (SD 2.16). There were 9 boys (60.0%). All the participants were diagnosed with MD and had comorbid ADHD. Ten participants (66.7%) also had RD.

Effects of treatment programs for SLD

Reading disorder

The results of the comparison of CLT-R scores before and after the treatment are presented in Table 2. After the treatment, in the word reading test—which is a reading achievement test—the accuracy rate and fluency score for meaningful and meaningless words increased (accuracy rate of the Word Attack test, p=0.001; fluency score of the Word Attack test, p<0.001; accuracy rate of the Nonword Decoding test, p<0.001; fluency score of the Nonword Decoding test, p<0.001). In the Paragraph Reading Fluency test (another read-

Table 1. Demographic and clinical characteristics of participants with RD or MD

Characteristics	RD			MD		
	Male (n=17)	Female (n=8)	Total (n=25)	Male (n=9)	Female (n=6)	Total (n=15)
Age (yr)	8.27±1.00	7.69±1.95	8.08±1.36	10.20±2.31	7.82±1.22	9.25±2.25
IQ	91.59±14.34	91.50±17.43	91.56±15.03	92.33±9.87	91.00±18.80	91.80±13.51
Education						
0 grade	1 (4.0)	3 (12.0)	4 (16.0)	-	-	-
1 grade	2 (8.0)	2 (8.0)	4 (16.0)	0 (0.0)	2 (13.3)	2 (13.3)
2 grade	9 (36.0)	1 (4.0)	10 (40.0)	3 (20.0)	3 (20.0)	6 (40.0)
3 grade	4 (16.0)	0 (0.0)	4 (16.0)	1 (6.7)	0 (0.0)	1 (6.7)
4 grade	1 (4.0)	1 (4.0)	2 (8.0)	2 (13.3)	1 (6.7)	3 (20.0)
5 grade	0 (0.0)	1 (4.0)	1 (4.0)	0 (0.0)	0 (0.0)	0 (0.0)
6 grade	-	-	-	1 (6.7)	0 (0.0)	1 (6.7)
7 grade	-	-	-	1 (6.7)	0 (0.0)	1 (6.7)
8 grade	-	-	-	1 (6.7)	0 (0.0)	1 (6.7)
Total	17 (68.0)	8 (32.0)	25 (100.0)	9 (60.0)	6 (40.0)	15 (100.0)
Comorbidity						
ADHD	16 (64.0)	6 (24.0)	22 (88.0)	9 (60.0)	6 (40.0)	15 (100.0)
MD	8 (32.0)	4 (16.0)	12 (48.0)	-	-	-
RD	-	-	-	6 (40.0)	4 (26.7)	10 (66.7)

Values are presented as mean±standard deviation or number (%). ADHD, attention deficit hyperactivity disorder; IQ, intelligence quotient; MD, mathematics disorder; RD, reading disorder

Table 2. Changes of the CLT-R after treatment

	Participants	Pre	Post	z	p	ES (d)
Word Attack test						
AR	25	76.70±34.85	98.60±2.98	-3.364	0.001	-0.93
FS	24	33.50±24.06	50.71±16.59	-3.743	<0.001	-0.87
Nonword Decoding test						
AR	25	57.90±34.74	91.30±7.50	-4.013	<0.001	-0.92
FS	24	13.19± 9.90	25.76±7.99	-4.286	<0.001	-1.00
Paragraph Reading Fluency test						
AR	18	85.95±14.48	96.70±5.18	-2.841	0.004	-0.78
FS	17	38.60±17.65	58.29±14.75	-3.621	<0.001	-1.00
Nonword Repetition test						
AR	25	76.50±13.44	86.17±12.83	-2.488	0.013	-0.60
Rapid Automatized Naming test						
N-MRT	25	46.64±18.96	33.56±9.41	4.123	<0.001	0.98
L-MRT	25	52.12±37.54	33.76±10.00	3.158	0.002	0.74
O-MRT	25	66.92±17.52	55.36±16.55	3.073	0.002	0.72
Letter-Sound Matching test						
AR	21	66.90±14.21	79.64±13.72	-2.840	0.005	-0.74

Values are presented as mean±standard deviation or number. AR, accuracy rate; CLT-R, Comprehensive Learning Test-Reading; d, Cohen's d; ES, effect size; FS, fluency score; L-MRT, letter-mean reaction time; N-MRT, number-mean reaction time; O-MRT, object-mean reaction time

Table 3. Changes of the CLT-M after treatment

	Participants	Pre	Post	z	p	ES (d)
Whole Number Computation test						
AR	15	55.30±30.52	86.16±11.95	-3.408	0.001	-1.00
FS	15	5.61±4.01	9.60±3.06	-3.296	0.001	-1.00
Numerical Comparison test: Magnitude						
AR	15	94.33±10.50	99.33±1.76	-1.980	0.048	-0.82
MRT	15	1657.40±505.31	1497.30±584.05	1.704	0.088	0.50
Numerical Comparison test: Distance						
AR	15	81.00±12.28	87.33±10.33	-2.046	0.041	-0.64
MRT	15	2509.80±613.26	2569.69±877.43	0.000	>0.999	0.00
Enumeration of Dot Group test						
AR	15	91.00±11.68	94.67±10.26	-1.491	0.136	-0.58
MRT	15	3068.27±637.04	2978.42±1201.45	0.738	0.460	0.22
Number Line Estimation test						
MER	15	16.46±8.98	9.64±4.92	2.556	0.011	0.75
MRT	15	2759.07±468.25	3407.47±907.54	-2.417	0.020	-0.73

Values are presented as mean±standard deviation or number. AR, accuracy rate; CLT-M, Comprehensive Learning Test-Mathematics; d, Cohen's d; ES, effect size; FS, fluency score; MER, mean error rate; MRT, mean reaction time

ing achievement test), the accuracy rate and fluency score also increased (accuracy rate, p=0.004; fluency score, p<0.001). Further, the accuracy rates for phonological working memory and letter−sound matching ability increased (Nonword Repetition test, p=0.013; Letter−Sound Matching test, p=0.005). Reaction time decreased for all number, letter, and object stimulus items in the RAN test (number, p<0.001; letter, p=0.002; object, p=0.002).

Mathematics disorder

The results of the CLT-M subtests are listed in Table 3. After the treatment, in the arithmetic test—which is a math achievement test—the accuracy rate and fluency score increased (accuracy rate for all computation tests, p=0.001; fluency score, p=0.001). Further, the accuracy rates increased in the magnitude and distance comparison tests, and the error rate decreased in the Numerical Comparison test (accuracy rate for the Magnitude Comparison test, p=0.048; accuracy rate for the Distance Comparison test, p=0.041; error rate for the Number Line Estimation test, p=0.011). There was no change in the reaction time of the Magnitude Comparison test and the Distance Comparison test, but the reaction time increased in the Number Line Estimation test (p=0.020). Lastly, there was no change in the Enumeration of Dot Group test.

DISCUSSIONS

In this study, we observed an overall improvement in children with RD after the treatment that was focused on phonological awareness training. Both the accuracy rate and the fluency score in word reading (meaningful/meaningless) and paragraph reading improved, reflecting the level of reading achievement. This reveals that this treatment program can help children with RD to read more accurately and fluently at both word and paragraph levels. In addition, the improvement in the results of the Nonword Repetition test, the Letter−Sound Matching test, and the RAN tests suggest that phonological awareness ability, grapheme correspondence ability, and fluency were also improved after the treatment, which is consistent with the results of previous studies [18,19]. To determine the relationship between reading achievement and phonological awareness ability, an additional correlation analysis was conducted by calculating the differences between the pre- and post-test for each subtest. The accuracy of the Word Attack test was negatively correlated with the reaction time of the RAN tests (number, r=-0.577, p=0.003; letter, r=-0.416, p=0.039), the fluency score of the Word Attack test showed a negative correlation with the RAN test (number, r=-0.550, p=0.005). The accuracy of the Nonword Decoding test showed a negative correlation with that of the RAN test (number, r=-0.547, p=0.005), and the fluency score showed a positive correlation with the accuracy of the Nonword Repetition test (r=0.420, p=0.041). These results suggest that improvements in phonological awareness and subcortical information processing speed are associated with better reading achievement.

We also found that our MD treatment program, which was intended to enhance number sense, improved the accuracy rate and fluency score on the arithmetic test, which reflects math learning achievement. The program also improved the accuracy rates for Numerical Comparison tests (Magnitude and Distance) and error rate in the Number Line Estimation test, which evaluated the degree of number sense. This finding suggests that improvement in number sense and subitizing ability through the treatment induces a subsequent improvement in math achievement. It is also in line with the results of previous studies [10,20,30]. To determine the relationship between math achievement and number sense ability, a correlation analysis was conducted. We found that the accuracy rate of the Whole Number Computation test measuring math achievement was positively correlated with the accuracy rate of the Magnitude Comparison test ($r=0.561$, $p=0.029$).

The reaction time, however, did not decrease or increase after the MD treatment. This may be because of compensatory speed maintenance or a slowdown in improving the accuracy; a so-called speed−accuracy trade off may have occured [31]. In addition, no difference was observed in the Enumeration of Dot Group test, which represents a subitizing ability. This was presumed to reflect the ceiling effect of the subtest, as the accuracy rate of the enumeration test before the treatment was 91%.

We also found that most children with SLD encountered in actual clinical situations had attention problems, and more than half had other comorbid disorders. This suggests that a comprehensive evaluation considering multiple aspects of learning ability should be applied to children and adolescents with learning difficulties, and that comprehensive, integrated, and individually tailored therapeutic and educational treatments—that are based on the specific evaluation results—should be provided together [5]. Therefore, close collaboration between medical, educational, and administrational experts is necessary.

The significance of this study is as follows. First, we assessed the study participants using objective and structured tools and applied the same organized treatment programs; therefore, the results of this study are more reliable than those of most previous studies on SLD. Second, in real situations, because children with SLD often have ADHD, it would be most effective to improve attention prior to implementing programs to remediate SLD problems. While most previous studies did not consider the assessment or treatment of attention issues, we first stabilized ADHD symptoms and then provided treatment programs for SLD, not only to minimize the effect of ADHD symptoms, but also to maximize the effectiveness of learning disorder treatment. Third, we conducted an objective evaluation of phonological awareness and number sense, which are core causes of RD and MD, and found that improvements in reading and math achievement were related to improvements in core neurocognitive deficits. Fourth, we provided programs for an average of 23 months for RD and 18 months for MD, which were longer than in other Korean studies [18,20]. This verified the treatment effect over a relatively long period.

The limitations of this study are as follows. First, because the study involved children and adolescents who visited a single child and adolescent clinic in Seoul, the representativeness of the sample may be insufficient. Second, we compared the pre- and post-treatment results only in the treatment group; therefore, it is necessary to conduct a future study with a control group and a blind assessment. Third, since this was a natural study, not an experimental study that controlled situations, only the influence of attention drugs was excluded, and the influence of other factors (e.g., average math study time) was not excluded.

CONCLUSION

In this study, the effectiveness of treatment programs for children and adolescents RD or MD, which enhanced phonological awareness and number sense, respectively, was verified to improve core neurocognitive deficits and related academic achievement in children and adolescents with RD or MD in Korea.

Availability of Data and Material

The datasets generated or analyzed during the study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: Hanik Yoo. Data curation: Hannah Huh. Formal analysis: Hyunju Lee. Investigation: Inhye Song, Woo Young Kim, Eun Kyoung Lee. Methodology: Hanik Yoo. Project administration: Hannah Huh. Resources: Jaesuk Jung, Cheon Seok Suh, Hanik Yoo. Supervision: Hanik Yoo. Validation: Hyunju Lee. Visualization: Hyunju Lee. Writing—original draft: Hyunju Lee. Writing—review & editing: Hanik Yoo.

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